Surgical and endovascular intervention for infrainguinal vein graft stenosis

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Purpose: The purpose of this study was to evaluate the stenosis-free patency of open repair (vein-patch angioplasty, interposition, jump grafting) and percutaneous transluminal balloon angioplasty (PTA) of 144 vein graft stenoses that were detected during duplex scan surveillance after infrainguinal vein bypass grafting.
Methods: Patients who underwent revision of an infrainguinal vein bypass graft were analyzed for type of vein conduit, vascular laboratory findings leading to revision, repair techniques, assisted graft patency rate, procedure mortality rate, and restenosis of the repair site.
Results: The time of postoperative revision ranged from 1 day to 133 months (mean, 13 months). One hundred eighteen primary and 26 recurrent stenoses (peak systolic velocity, >300 cm/s) in 52 tibial and 35 popliteal vein bypass grafts were identified by means of duplex scanning. The repairs consisted of 77 open procedures (vein-patch angioplasty, 28; vein interposition, 33; jump graft, 9; primary repair, 3) and 67 PTAs. No patient died as a result of intervention. Cumulative assisted graft patency rate (life-table analysis) was 91% at 1 year and 80% at 3 years. At 2 years, cumulative assisted graft patency rate was comparable for saphenous vein grafts (reversed, 94%; in situ, 88%; nonreversed, 63%) and alternative vein grafts (89%). Stenosis-free patency rate at 2 years was identical (P = .55) for surgical intervention (63%) and endovascular intervention (63%) but varied with type of surgical revision (P = .04) and time of intervention (<4 months, 45%; >4 months, 71%; P = .006). The use of duplex scan–monitored PTA to treat focal stenoses (<2 cm) and late-appearing stenoses (>3 months) was associated with a stenosis-free patency rate that was 89% at 1 year. After intervention, the alternative vein bypass grafts necessitated twice the reinterventions per month of graft survival (P = .01). Bypass graft to the popliteal versus infrageniculate arteries, site of graft stenosis (vein conduit, anastomotic region), and repair of a primary versus a recurrent stenosis did not influence the outcome after intervention.
Conclusion: The revision of duplex scan–detected vein graft stenosis with surgical or endovascular techniques was associated with an excellent patency rate, including when intervention on alternative vein conduits or treatment of restenosis was necessary. When PTA was selected on the basis of clinical and duplex scan selection criteria, the endovascular treatment of focal vein graft stenosis was effective, durable, and comparable with the surgical revision of more extensive lesions. (J Vasc Surg 1999;29:60-71.)

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The vascular laboratory surveillance of infrainguinal vein bypass grafts to detect stenosis from intimal hyperplasia, fibrous stricture, or atherosclerosis has become a practice standard.[1-4] The strategy of postoperative surveillance is used not only to detect the failing graft but also to assist the surgeon in deciding when to intervene and what type of intervention to choose to correct the graft abnormality. No consensus exists regarding the "best" secondary procedure for postimplantation stenotic lesions. The repair technique and the outcome of graft revision depend

on a number of factors including the following: the length of stenosis, the location (anastomosis, venous conduit, adjacent native artery), the type of vein conduit, the time of occurrence, and the precision of the repair itself. Surgical repairs, such as vein-patch angioplasty, interposition grafting, and jump grafting, are preferred on the basis of the low morbidity of intervention, the high early patency rate, and a long-term assisted graft patency rate in excess of 80%.[1,5-7] By comparison, the use of percutaneous transluminal angioplasty (PTA) to correct vein graft stenosis is more controversial. The applicability and durability of PTA have been questioned by some vascular groups who do not recommend its use, yet other groups have reported success rates in excess of 80%.[8-10] No study has compared surgical management with endovascular management of vein graft stenoses in terms of graft types, assisted graft patency rates, or the need for reintervention. In this retrospective review, the morbidity rate and the stenosis-free patency rate of open surgical repair were compared with endovascular angioplasty in the management of 118 primary and 26 recurrent vein graft stenoses in 87 infrainguinal vein bypass grafts that were detected with duplex scan surveillance and repaired with techniques selected on the basis of the clinical and duplex ultrasound scan features of each stenosis.

MATERIAL AND METHODS

Study population. Patients who underwent revision of an infrainguinal vein bypass graft from 1992 to February 1998 were identified through the vascular registries of the University of South Florida Division of Vascular Surgery and the JA Haley Veterans Affairs Hospital. During this time interval, 528 infrainguinal vein bypass grafting procedures were performed. In 84 patients (87 bypass grafts), 118 primary sites of stenosis were detected and subjected to repair. The vascular laboratory, hospital, and outpatient clinic records were reviewed, and the data were tabulated for type of vein bypass graft conduit, duplex scan findings leading to revision, repair techniques, assisted graft patency rate, restenosis of the repair site, and procedure mortality rate. Patients with hemodynamic vein graft failure caused by proximal prosthetic limb occlusion (n = 1) and vein graft occlusions (n = 2) that were not successfully opened with catheter-directed thrombolysis or salvaged with thrombolysis alone were not included. The mean follow-up time after graft revision was 17 months. Four patients were lost to follow-up beyond 6 months of graft revision.

The study group consisted of 87 grafts in 59 men and 25 women (mean age, 66 years; range, 31 to 84 years). Fifty-three grafts underwent a single revision, and 34 grafts had multiple revisions for metachronous or recurrent graft stenosis. The indications for bypass grafting in the 87 lower limbs included critical ischemia manifested as rest pain, ulceration, or gangrene in 79 limbs, claudication in 6 limbs, and asymptomatic popliteal aneurysm in 2 limbs. Bypass grafting techniques used at the primary procedure included the following: in situ saphenous vein bypass (n = 30), reversed saphenous vein bypass (n = 19), nonreversed translocated saphenous vein bypass (n = 16), and alternative vein bypass (n = 22). The average time from bypass grafting procedure to the first or "primary" graft revision procedure was 13 months (range, 1 day to 133 months). A total of 144 interventions were performed on 50 femorotibial, 35 femoropopliteal, and 2 popliteal-pedal vein bypass grafts to correct 94 initial graft stenoses, 24 metachronous lesions, which developed at another site during the follow-up period, and 26 restenoses after intervention.

Vascular laboratory testing. Infrainguinal vein bypass abnormalities were identified with a postoperative surveillance program that included clinical evaluation, Doppler scan–derived limb pressure measurements, and color duplex scanning. In general, the graft surveillance was performed before discharge, at 4 to 5 weeks after surgery, and at 3-month or 6-month intervals thereafter on the basis of vein bypass graft type and the presence or absence of a duplex scan–detected bypass graft abnormality. Beyond 2 years after operation or revision, annual graft surveillance was performed if the prior duplex scan results were normal and if atherosclerotic disease risk factors (hypertension, serum cholesterol level, and tobacco use) were under control. At each postoperative evaluation, the entire vein graft, including both anastomoses and adjacent native artery, was visualized and the measurements of peak systolic blood flow velocity (PSV) were recorded at several sample sites along the bypass graft and in the anastomotic regions. If color Doppler imaging identified a stenosis, the measurements of PSV at the stenosis and the PSV velocity ratio (Vr), where $Vr = PSV_{\text{at lesion}}/PSV_{\text{proximal}}$, were recorded and the lesions with PSV more than 300 cm/s or velocity ratio more than 3.5 were selected for repair. The lesions that were identified with serial duplex scans to progress in stenosis severity or that were associated with the development of low graft flow velocity (<45 cm/s) were recommended for repair. Angiography was performed before intervention on a selective basis—when duplex scan–detected

stenoses were selected for PTA and to evaluate long-segment or multiple graft lesions, particularly if lesions in the inflow or outflow native arteries were also detected. Twenty-four of the 77 surgical revisions (31%) were performed on the basis of duplex scan findings alone.

Techniques of vein bypass graft revision. Open surgical and endovascular techniques that were used to repair stenotic bypass graft segments varied with anatomic site, lesion length, conduit diameter, and appearance time from the primary grafting procedure. In general, vein-patch angioplasty or PTA was used to treat focal (<4 cm) postimplantation lesions (myointimal hyperplasia, vein fibrous, sclerotic valves). More extensive longer lesions, such as sclerotic vein segments, multiple graft stenoses, and diffuse myointimal or atherosclerotic lesions that involved perianastomotic inflow or runoff arteries, were treated with interposition or "jump graft" techniques. Operative techniques of open surgical repair, including the use of intraoperative duplex scanning of the repair site to exclude residual stenosis, have been previously detailed.[7]

On the basis of clinical outcomes gleaned in the past 10 years, we have found the appearance time of a graft stenosis to be an important criterion for the selection of PTA. Lesions that are identified in the early postoperative period are related to poor quality vein or procedure problems (vein torsion, graft entrapment) and necessitate surgical attention. Lesions that develop into high-grade stenoses beyond 3 months after the primary procedure are selected for endovascular treatment if the lesion features are those of focal (<2 cm in length) stenosis and if the vein bypass graft has a good caliber (>3.5 mm). In selected patients, early PTA has been performed to correct a native inflow artery stenosis or used when surgical intervention was not possible because of the patient's medical condition or wishes. During the past 2 years, duplex scan monitoring of the PTA procedure was performed to ensure the normalization of the PTA site hemodynamics (PSV, <180 cm/s; Vr, <2.0) within the graft segment subjected to balloon dilation.

The patients who were recommended to undergo vein graft PTA were treated as outpatients and lodged in a 23-hour observation unit. After a preintervention angiography to confirm the appropriate anatomic features of a stenosis suitable for PTA, the patients were administered systemic heparin to prolong the activated clotting time of more than 250 seconds and balloon dilation of the stenotic vein conduit or native artery segment was performed. The initial balloon diameter size was chosen on the basis of preintervention duplex scan findings. In general, the inflation pressures and times were in the range of 8 to 12 atm and 45 seconds to 1 minute in duration. If duplex scan monitoring of the PTA site identified residual stenosis (PSV, >180 cm/s; Vr, >2.0), repeat transluminal dilation was performed with either prolonged inflation time (2 to 3 minutes) or a larger (1 to 2 mm) balloon.

Data analysis. Estimations of cumulative assisted graft patency rate and stenosis-free patency rate (ie, graft was patent and no intervention for recurrent stenosis was performed) were performed with the Kaplan-Meier life-table method beginning at the time of graft revision. Statistical analysis was performed and compared the outcome of surgical versus endovascular (PTA) intervention on both primary and recurrent stenosis and the time to intervention, bypass graft type, and surgical repair technique. The differences in life-table patency rate were analyzed with the log-rank test, with a P value of less than .05 considered significant. A comparison of graft revision frequency relative to type of vein conduit was performed with the likelihood ratio test on the basis of the Poisson distribution.

RESULTS

The site and clinical features of the 118 sites of primary stenosis and the 26 sites of restenosis are detailed in Table I. One quarter of the patients had symptoms of limb ischemia (claudication, 16; ulceration, 10; rest pain, 6) at the time of graft revision. On the basis of histologic examination and operative findings, the most common graft lesion was myointimal hyperplasia, with the predominant location in the vein conduit or at the distal anastomotic region. All the submitted explanted graft specimens (n = 34) showed wall thickening with varying degrees of cellularity and the histology of myointimal hyperplasia. In general, the graft abnormalities that were repaired within 1 month were not submitted because these early lesions represented residual defects caused by technical error (incomplete valve lysis, graft torsion) or intrinsic vein conduit abnormality (sclerosis, small diameter). Metachronous graft stenosis developed in 24 bypass grafts at a mean of 4.2 months after intervention for a stenosis at another site. One half of the alternative vein bypass grafts developed multiple sites of stenosis. At 20 sites at which a primary graft stenosis developed, the intraoperative or predischarge duplex scan had shown a mild (PSV, 150 to 230 cm/s) residual stenosis. The sites of stenoses that were revised within the 4 months of operation

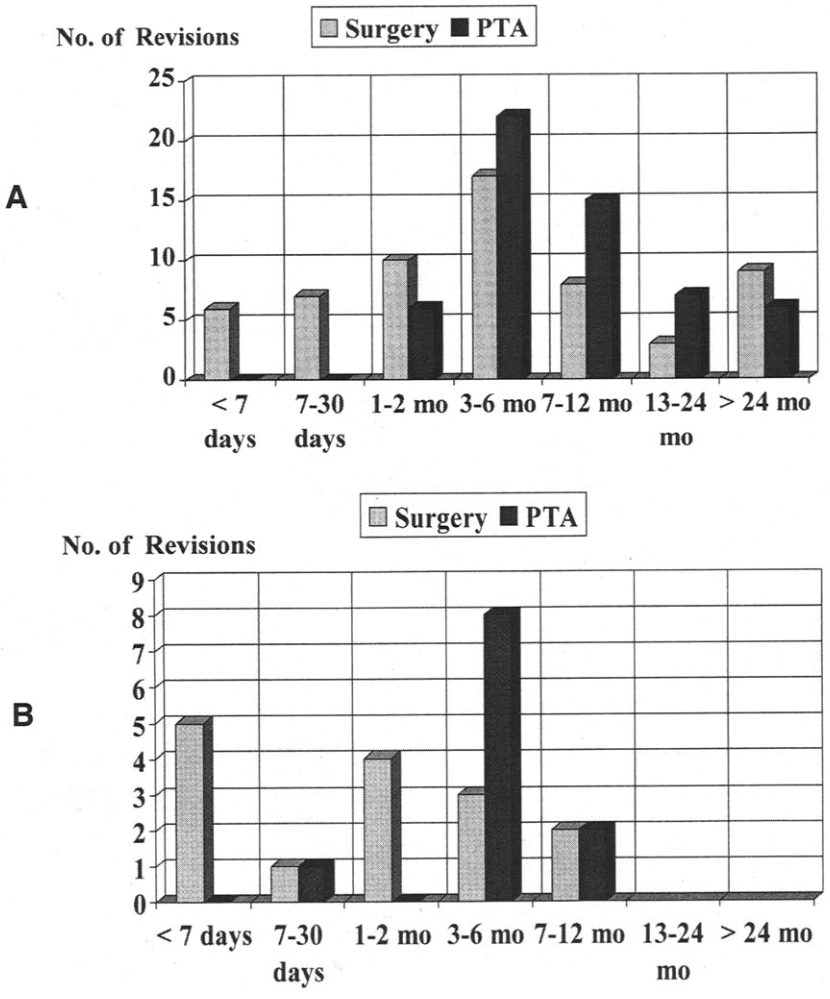

Fig 1. Number of surgical and endovascular (percutaneous transluminal balloon angioplasty) interventions for 118 primary **(A)** and 26 recurrent **(B)** vein graft stenoses relative to postintervention time interval.
PTA, Percutaneous transluminal angioplasty.

showed decreased stenosis-free patency rates at 2 years (<4 months, 45%; >4 months, 71%; $P = .006$).

Intervention at 144 sites of primary and recurrent stenosis consisted of 67 PTAs and 77 open surgical repairs, including vein-patch angioplasty (n = 33), interposition graft (n = 30), jump graft (n = 11), and primary repair (n = 3). Stenosis severity on the basis of duplex scan peak velocity criteria was similar for the lesions that were treated surgically (373 ± 45 cm/s) and with PTA (368 ± 42 cm/s). Nonfocal stenosis (length, >2 cm) was more commonly treated with surgery (27 of 77 [35%]) than with PTA (5 of 67 [7%]). Twice the number of patients who underwent surgical revision were symptomatic as compared with the patients who underwent PTA. The frequency of surgical and endovascular repair of primary and recurrent graft stenosis relative to the postoperative time interval is shown in Fig 1. Surgical repair was used more frequently for early-appearing (<4 months) primary lesions (30 of 37 interventions [81%]) after bypass grafting, and PTA was the most common method of stenosis repair beyond 4 months (49 of 81 interventions [60%]). Of the 7 surgical revisions that were performed within 1 week of the operation, two grafts remained patent, four necessitated subsequent reintervention for stenosis, and one was occluded. Overall, three quarters of the revisions (92 of 118) for primary graft stenosis were performed within the first postoperative year. In the 87 grafts, a total of 144 secondary procedures were performed (average, 1.7 interventions/graft; range, 1 to 6 revisions).

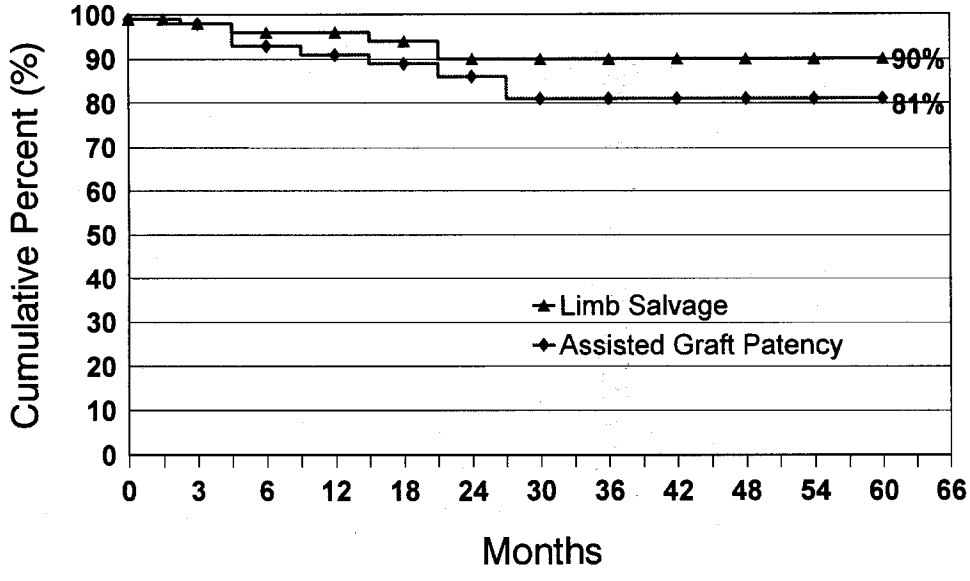

Fig 2. Limb salvage rates and cumulative-assisted graft patency rates (life-table method) of 87 grafts revised for duplex scan–detected stenosis (peak systolic blood flow velocity, >300 cm/s; velocity ratio, >3.5).

Table I. Site and clinical characteristics of 118 primary stenoses and 26 recurrent stenoses revised in 87 infrainguinal vein bypass grafts

	Primary stenosis	*Recurrent stenosis*
Site of stenosis		
Proximal anastomotic region	24	6
Vein conduit	48	11
Distal anastomotic region	46	9
Type of bypass graft		
Femoropopliteal (n = 35)	45	13
Femorotibial (n = 50)	71	13
Popliteal-pedal (n = 2)	2	0
Bypass grafting technique		
In situ saphenous vein (n = 30)	37	9
Reversed saphenous vein (n = 19)	27	8
Nonreversed, translocated saphenous (n = 16)	22	6
Alternative or spliced (n = 22)	32	3
Postoperative time to intervention		
<4 months	37	13
>4 months	81	13

Table II. Type of intervention for 144 graft stenoses relative to bypass graft type

	Surgery	*PTA*
Bypass graft type		
In situ saphenous	25	21
Reversed saphenous	21	14
Nonreversed translocated saphenous	14	14
Alternative vein	17	18

PTA, Percutaneous transluminal balloon dilation.

Surgical repair and PTA were applied with equal frequency in revision of the various types of saphenous and alternative vein bypass grafts (Table II). At the 118 sites of primary stenosis, 96 sites necessitated a single revision, 19 necessitated 2 interventions, 2 necessitated 3 revisions, and 1 necessitated 4 interventions. All the grafts that necessitated more than one revision remained patent, and no limb loss occurred in this patient cohort. Overall, the limb salvage rate was 96% at 1 year and 90% at 3 years (Fig 2). Five below-knee amputations were performed after graft failure, including one in a patient with diabetes with end-stage renal failure and failure of a transmetatarsal amputation to heal despite a patent popliteal-pedal bypass grafting procedure.

No patient died as a result of intervention. Nine patients died during the mean follow-up interval of 17 months, which resulted in a patient survival rate of 89%. The cumulated assisted graft patency rate after revision was 91% at 1 year, 84% at 2 years, and 79% at 3 years (Fig 2) and at 2 years was comparable (P = .26) for saphenous (in situ, 88%; reversed, 94%; nonreversed, 63%) and alternative (89%) vein grafts. Ten graft failures occurred (mean time to occlusion of 9 months after revision)—six were caused by multiple segmental stenosis in a small diameter vein conduit,

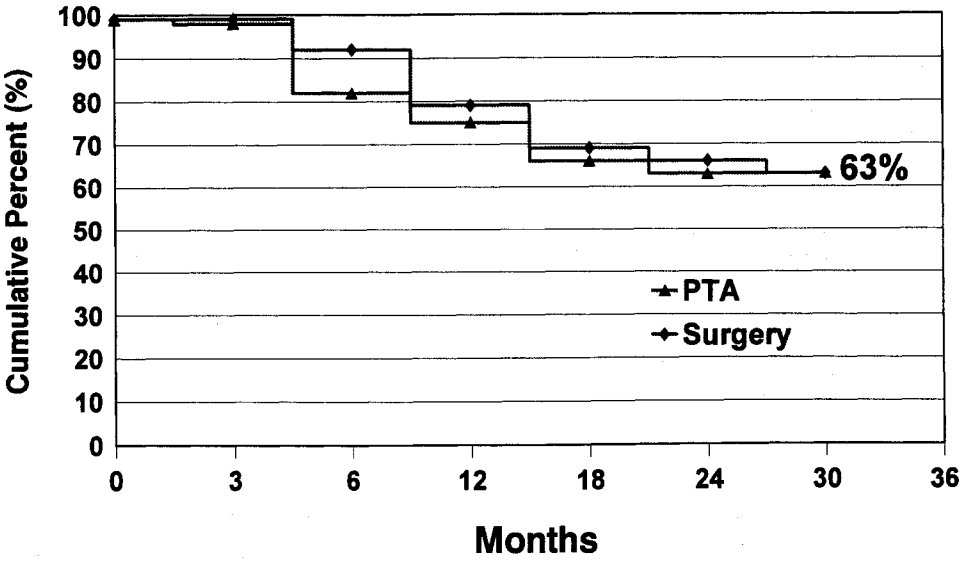

Fig 3. Stenosis-free patency rate (endpoint of graft occlusion and intervention for restenosis) for surgical and endovascular (percutaneous transluminal balloon angioplasty) repair of 118 sites of primary stenosis in 87 grafts.
PTA, Percutaneous transluminal angioplasty.

Table III. Number of restenoses repaired and graft occlusions following surgical and endovascular intervention for primary (n = 118) graft stenosis

	No. of primary stenoses repaired	*No. of secondary stenoses repaired**	*No. of graft occlusions*
Type of surgical repair			
Vein-patch angioplasty	25	8	2
Interposition graft	25	5	4
Jump/sequential bypass graft	9	2	2
Primary repair	3	0	0
Endovascular repair			
PTA	36	5	0
Duplex scan–monitored PTA	20	6	2
Total	118	26	10

PTA, Percutaneous transluminal angioplasty.
Selection criteria: stenosis, <2 cm; vein diameter, >3.5 mm; appearance time, >3 months after primary procedure or intervention for graft stenosis.
*Restenosis at site of prior surgical repair or percutaneous transluminal angioplasty.

two from repair site failure, and two from progression of outflow tract atherosclerotic disease (Table III). Five redo bypass grafting procedures were performed for critical ischemia. The incidence rate of graft occlusion and the need for reintervention for restenosis (ie, stenosis-free patency) were similar ($P = .55$) at 2 years after surgical (63%) or endovascular (63%) intervention (Table IV; Fig 3). In the treatment of focal graft stenosis, the 1-year stenosis-free patency rate of PTA (n = 56) was 66% and comparable with the 76% stenosis-free patency rate of vein-patch angioplasty (n = 25; Table III; Appendix). No difference in outcome was observed in the treatment of primary sites of stenosis versus restenosis after intervention. The stenosis-free patency rate at 2 years was 63% for primary lesions and 79% for restenoses ($P = .2$; Fig 4). Alternative vein bypass grafts necessitated twice the reinterventions per month of graft survival as compared with in situ or reversed saphenous vein grafts ($P = .01$), and only two alternative vein grafts failed. The revisions of infrageniculate bypass grafts were as successful as with the popliteal bypass grafts ($P = .86$), and the site of graft stenosis (vein conduit versus anastomotic region) did not influence outcome after the intervention ($P = .77$). The secondary revisions for restenosis (n = 26) were successful with an equivalent stenosis-

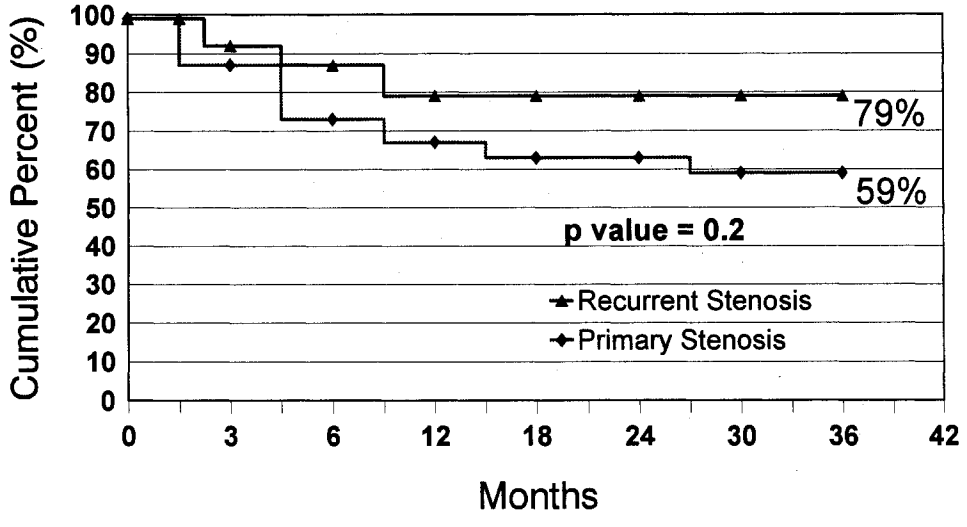

Fig 4. Stenosis-free patency rate of graft revision for primary (n = 118) or recurrent (n = 26) graft stenosis.
P value = .2, with log-rank test.

Table IV. Crude patency rates and stenosis-free patency rates (life-table method) after surgical or endovascular repair of 118 sites of primary graft stenosis

	Crude patency rate (%)	*Cumulative 1-year* patency rate (%)*	*Assisted 2-year† patency rate (%)*	*P value*
Type of intervention				
PTA (n = 56)	65	66	63	.55
Surgery (n = 62)	69	69	63	.55
Vein-patch angioplasty (n = 22)	82	76	76	.04
Interposition graft (n = 23)	57	47	47	
Jump graft (n = 10)	82	88	58	
Primary repair (n = 3)	100			
Time of intervention				
<4 months (n = 36)	53	51	45	.006
>4 months (n = 80)	75	74	71	
Bypass graft outflow artery				
Popliteal (n = 45)	67	66	58	
Tibial/pedal (n = 71)	69	68	68	.86
Site of stenosis				
PAG (n = 24)	71	70	61	.77
Vein conduit (n = 47)	72	67	67	.77
DAG (n = 44)	61	64	59	.77

PAG, Proximal anastomotic graft region; *DAG,* distal anastomotic graft region including outflow artery.
*Life-table analysis, standard error less than 7%.
†Life-table analysis, standard error less than 10%.

free patency rate for PTA (9 of 11; 82%) and surgery (13 of 15; 87%). No graft that was revised for recurrent stenosis failed during the follow-up interval.

Beginning in 1996, vein graft PTA procedures were performed with duplex scan monitoring to detect residual stenosis. Twenty-six patients have undergone duplex scan–monitored PTA, which accounts for 75% of the PTA procedures during this time interval. In 21 of the 26 procedures, the anatomic and clinical criteria (appearance time, >3 months; stenosis length, <2 cm; vein diameter, >3.5 mm) for use of PTA were met and 19 of the 21 sites remained patent (90%) at 1 year. The 1-year stenosis-free patency rate in this group of patients was 89% as compared with 61% ($P = .03$) in the remaining PTA procedures. Duplex scan evaluation identi-

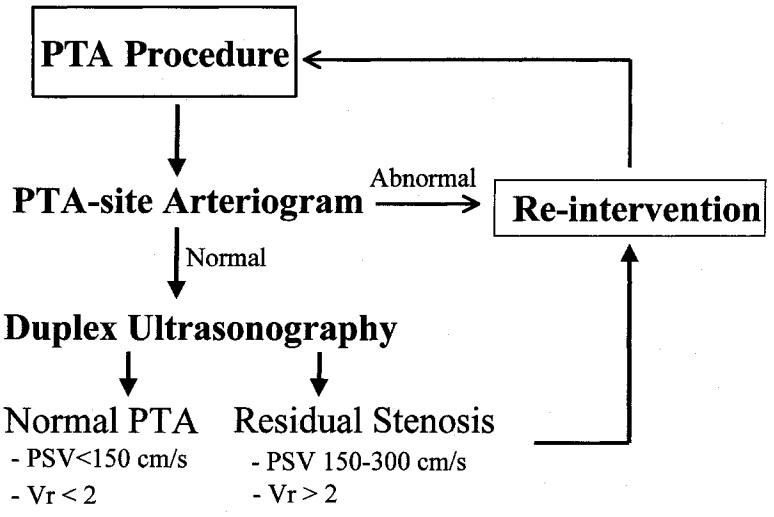

Fig 5. Evaluation algorithm of vein graft percutaneous transluminal balloon angioplasty with arteriography and duplex ultrasound scanning.
PTA, Percutaneous transluminal angioplasty; *PSV,* peak systolic blood flow velocity; *Vr,* velocity ratio.

fied residual stenosis during nine PTA procedures, which prompted reintervention with a larger balloon (n = 5) or a prolonged inflation time (n = 4). Eight of these PTA sites remained free of stenosis during the follow-up interval (mean, 9 months), and one site restenosed at 5 months and underwent a second PTA successfully.

DISCUSSION

This study confirms the findings of other vascular groups concerning the excellent assisted graft patency rates of infrainguinal vein bypass grafts that are subjected to revision while patent to repair a duplex scan–detected graft stenosis. The assisted graft patency rate of 80% at 3 years was similar to that of a prior report that dealt with revision of in situ saphenous vein arterial bypass grafts (89% at 3 years).[11] The important differences with the present study were the expanded application of PTA to dilate focal graft lesions and the intervention on bypass grafts of various types, including alternative vein bypass grafts. When PTA was applied selectively, the outcome as measured with stenosis-free patency rate was similar to open surgical repair (63% versus 63% at 2 years; life-table analysis). Although the reintervention rate after PTA (22%) was higher than after surgical revision (14%), fewer graft failures occurred (2 versus 8), which accounted for the identical stenosis-free patency rate. The lesions that were treated with open repair versus PTA did differ both in appearance time and in extent of lesion, with PTA used in selected patients with focal lesions. Other important findings of this study included the similar outcome of surgical or endovascular intervention regardless of the graft type, treatment of primary versus recurrent stenosis, and site of graft stenosis. The clinical relevance of these observations involves the use of anatomic features and appearance time of stenosis as the major criteria for recommending open surgical repair or PTA. This approach, when combined with continued duplex scan surveillance, was effective in maintaining graft patency. The graft failure rate was 11%, with the predominant causes being development of diffuse/multiple vein graft strictures or atherosclerotic disease progression not amenable to surgical or endovascular intervention. Nehler et al[7] reported a 96% assisted graft patency rate after the exclusively surgical revision of reversed vein bypass grafts but included in the analysis the treatment of inflow and outflow occlusions, lesions associated with low risk of failure after bypass grafting. Our study data indicate that the success of intervention for vein graft stenosis caused by myointimal hyperplasia or fibrous stricture may be more dependent on the technical precision of the repair procedure and the pathobiology at the site that produced progressive lumen reduction. Early lesions have been shown to be more biologically active and thus may be more prone to recurrence early after surgical intervention and may not be suited for treatment with PTA.[12]

We believe that the use of duplex scan criteria for PTA application is important for a successful outcome. This includes the treatment of focal lesions in

good caliber vein conduits beyond the early postoperative period of graft arterialization and the monitoring of the PTA procedure with duplex scanning to detect and treat residual stenosis. Our initial experience with duplex scan–monitored PTA of vein graft stenoses indicates that this type of surveillance is useful because a residual stenosis was identified in 9 of the 26 procedures despite angiogram results that indicated a successful intervention. Further PTA with either a prolonged inflation time or a 1-mm to 2-mm larger balloon normalized the PTA site hemodynamics, criteria that we have previously documented to be important for angioplasty site. In the treatment algorithm that is shown in Fig 5, duplex scan assessment that is performed after angiography confirms a widely patent bypass graft, no complication (vein rupture, distal embolization), and a less than 30% diameter reduction in residual stenosis. On occasion, it is prudent to accept a residual duplex scan–detected stenosis after PTA to avoid vein injury (ie, rupture) and then, if stenosis severity recurs, proceed with surgical intervention.

With the application of vascular laboratory graft surveillance, most of the patients with failing grafts now are identified earlier, typically while asymptomatic, and are associated with modest decreases (0.1 to 0.3) in ankle-brachial systolic pressure index as compared with initial postoperative values. A recent meta-analysis of infrainguinal bypass grafts with postoperative surveillance concluded that graft patency rate is improved but enhanced limb salvage rate (ie, reduction in amputations) has not been shown.[6] Although graft stenosis and other anatomic abnormalities can be accurately identified with duplex scanning, which grafts are at the highest risk for thrombosis and, therefore, should be revised is less clear. The cost of postoperative surveillance in terms of time and health care dollars is significant, but most surgeons, and certainly the patients themselves, feel that the detection of the failing graft before thrombosis is worthwhile. This study confirmed that the bypass grafts that were constructed with alternative veins are at the highest risk for developing a metachronous stenosis and that reintervention rates were twice as high as those observed after in situ or reversed saphenous vein bypass graft revision.

Duplex scan surveillance of infrainguinal vein bypass grafts that use the combination of high-velocity and low-velocity criteria identifies the grafts with a low flow and a pressure-reducing stenosis. The duplex scan features of stenosis include the presence of a "flow jet" in systole and visualized lumen reduction. Velocity criteria include increased velocities in both systole (>300 cm/s) and diastole (>75 to 100 cm/s) and peak systolic velocity ratios across the stenosis more than 3.4. Low graft flow criteria include velocities more than 45 cm/s in normal (no stenosis, diameter 5 mm or less) grafts, particularly if no diastolic flow is identified. In a prospective study, the application of these threshold criteria identified all the grafts at risk for thrombosis and only one lesion with these velocity criteria regressed.[14] We agree with recent reports that duplex scan results can be used without confirmatory arteriography to recommend graft revision to the patient who is asymptomatic.[15] Approximately one third of all the surgical revisions were performed on the basis of duplex scan findings alone, and all the patients who were selected for PTA underwent the planned endovascular procedure.

The goal of surveillance is not only to detect the failing graft but also to assist the surgeon in the decision of when to intervene and of which procedure would best correct the abnormality. The surgical options of vein-patch angioplasty, interposition grafting, and jump grafting have become the standard approach to repair of vein graft stenosis, and the application of PTA for graft revision is more controversial. In the current series, angioplasty was applied to stenoses in the venous conduit, at anastomotic sites, and at diseased outflow. Nearly half of all the vein bypass graft stenoses that were identified were managed with balloon dilation PTA. By contrast, in a previously published series by Bandyk et al,[1] only 17% of the stenoses were managed with PTA and applied to the venous conduit in only 5 cases. In another previous report, we identified clinical and anatomic duplex scan features that predict PTA success.[3] The criteria include stenosis severity, length of lesion, vein size, and appearance time (eg, peak velocity, >300 cm/s; Vr, >3.4; vein size, >3.5 mm; stenosis length, <2 cm; appearance time, >3 months after bypass grafting). On the basis of these results, we modified our management of vein graft stenosis such that the lesions with this criteria are managed with PTA. Working in concert with our interventional vascular radiologist colleagues, we have used duplex scanning during the PTA procedure to monitor the hemodynamic result of dilation. In a significant number of cases, 9 of 26 (34%), the procedure was modified entirely on the basis of the duplex scan findings. Additional endovascular treatment of the stenosed vein segment with either a larger balloon or a prolonged inflation time, improved velocity spectra, and a low incidence rate of restenosis (90% at 1 year) was

observed. The Montefiore group[16] reported a 66% 2-year graft patency rate after vein graft PTA when arteriography identified a concentric, short (<15 mm) stenosis in an otherwise normal vein bypass graft and treatment produced a normal angiographic appearance. This group observed poor results (17% patency rate) in treating the more complex lesions (multiple stenoses, recurrent lesion, small diameter vein). Direct surgical repair or vein graft replacement is recommended for the lesions that do not meet our duplex scan selection criteria (ie, early-appearing or long-segment stenosis and focal stenosis in small caliber vein conduits).

CONCLUSION

Revision of duplex scan–detected vein graft stenosis was associated with an excellent patency rate, including when the intervention on alternative vein conduits or the treatment of restenosis was necessitated. Color duplex scanning has an established role in the detection and surveillance of the failing infrainguinal bypass graft and has shown promise in stratifying lesions that are best treated with open (surgical) versus percutaneous balloon dilation. Approximately one third of the surgical revisions were undertaken on the basis of duplex scan findings alone. When PTA was used in conjunction with clinical (>3 months after surgery) and duplex selection criteria (<2 cm stenosis in >3.5-mm diameter vein conduit), endovascular treatment of focal vein graft stenosis was effective, durable, and comparable with a surgical revision of more extensive lesions.

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APPENDIX. LIFE-TABLE ANALYSIS OF CUMULATIVE STENOSIS-FREE PATENCY OF 118 PRIMARY GRAFT STENOSES RELATIVE TO SURGICAL REPAIR (N = 62) OR PERCUTANEOUS TRANSLUMINAL BALLOON ANGIOPLASTY (N = 56) AND ANALYSIS OF 26 SECONDARY REVISIONS

		No. sites failing					
Interval (mo)	No. sites at risk	Restenosis	Occlusion	No. grafts withdrawn*	Interval patency	Cumulative patency	Standard error (%)
Surgery							
0 to 1	62	0	0	0	1.0	1.0	
1 to 3	62	3	2	3	0.92	1.0	
3 to 6	54	3	4	4	0.87	0.92	3.5
6 to 12	43	4	1	8	0.88	0.79	5.3
12 to 18	30	0	1	10	0.97	0.69	6.3
18 to 24	19	1	0	4	0.95	0.66	6.6
24 to 30	14	0	0	2	1.0	0.63	7.3
30 to 36	12	0	0	2	1.0	0.63	7.3
36 to 42	10	0	0	4	1.0	0.63	7.3
42 to 48	6	0	0	2	1.0	0.63	7.3
PTA							
0 to 1	56	0	1	0	0.98	1.0	
1 to 3	55	9	0	0	0.82	0.98	1.8
3 to 6	46	4	0	3	0.89	0.82	5.1
6 to 12	39	4	0	8	0.90	0.75	5.8
12 to 18	27	1	0	11	0.96	0.66	6.6
18 to 24	15	0	0	5	1.0	0.63	6.9
24 to 30	10	0	1	7	0.90	0.63	6.9
30 to 36	2	0	0	1	1.0	0.53	10.7
Revision for recurrent stenosis							
0	26	0	0	0	1.0	1.0	
1 to 3	26	2	0	2	0.92	1.0	
3 to 6	22	1	0	1	0.95	0.92	5.4
6 to 12	20	2	0	9	0.90	0.88	6.7
12 to 18	9	0	0	5	1.0	0.76	9.5
18 to 24	4	0	0	0	1.0	0.76	9.5
24 to 30	4	0	0	1	1.0	0.76	9.5
30 to 36	3	0	0	0	1.0	0.76	9.5
36 to 42	3	0	0	1	1.0	0.76	9.5

*Reason for withdrawal of grafts was death or duration of follow-up interval.

DISCUSSION

Dr Gary F. Seabrook (Milwaukee, Wis). This work by Dr Avino and his colleagues at the University of South Florida represents another chapter in the manual that is now becoming a saga in the long-term care of the lower extremity vein graft. Indeed, these conduits are dynamic structures that mature and, unfortunately, sometimes age prematurely. Careful surveillance allows the detection of pathologic events that will progress to graft failure. This manuscript advances the cause of endovascular techniques in the salvage of the threatened venous conduit.

The authors conclude that the grafts that develop a focal stenosis after 3 months are likely to be successfully treated with percutaneous balloon angioplasty. Can you comment on this arterialization process that seems to stabilize after 3 months, and how that might relate to the character of the lesions that develop in these mature grafts?

Although not designed as a clinical trial, the report studies a similar number of lesions treated with endovascular techniques compared with those lesions treated with surgical approaches. Lesions were selected for endovascular treatment on the basis of clinical prejudices that would portend a good result, and assisted graft patency in the series was similar to stenotic sites treated with direct operative techniques. Interestingly, during the 6 years that data were accumulated, 87 conduits, or 17% of the grafts, necessitated revision. This compares with a 20% revision rate that our group identified and reported in 1990. The long-term patency rates in numerous, large, rigorously controlled series always are diminished by a group of grafts that cannot be preserved despite a policy of careful surveillance and aggressive intervention. We know that the need for modification of a conduit at the initial operation is a predictor of poor vein quality and of twice the likelihood that secondary procedures will be necessary to main-

tain long-term patency. Did the grafts in your series necessitate modification, and are such veins included in the group described as "alternative bypass grafts"? The message here is that some veins are going to function poorly as arterial substitutes.

Some focal stenoses that I have explored surgically look pretty ugly, not unlike the ulcerative lesions with intraplaque hemorrhage that we sometimes see at the focal stenosis of the internal carotid artery. Have you identified any duplex scan criteria that would preclude you from expanding a balloon across a lesion that might disintegrate and then embolize? Recognizing the rigorous scrutiny to which these authors subject their surgical results and the skepticism that I know they would apply to a controversial technique, the readers of the manuscript should consider the criteria presented here in selecting patients with focal graft stenosis for revision by percutaneous intervention.

Dr Anthony J. Avino. Thank you, Dr Seabrook, for your comprehensive review.

Regarding the arterialization of the vein grafts, we believe that early-appearing lesions represent more of a biologically active process of myointimal hyperplasia with a higher rate of nuclear proliferation. This may be related to the arterialization process in the vein graft. We have found that lesions that develop in the first 3 months are more likely to recur if treated with balloon angioplasty versus surgical revision.

In regards to your second question, we did include grafts that were modified at operation. They were not classified as "alternative vein grafts" on the basis of the need for intraoperative revision unless the vein conduit was arm or spliced vein. On the basis of our experience with intraoperative duplex scanning, residual lesions that were identified at the time of surgery and were corrected to a normal duplex scan behaved the same as grafts that did not require intraoperative revision. However, grafts that had a residual stenosis after intraoperative revision, or those with a moderate stenosis that was accepted, were more prone to develop vein graft stenosis during the early (<3 months) postoperative period. These lesions were more likely to be treated surgically because they often appeared and progressed to a high-grade stenosis in the first 3 months after operation.

Dr Anthony M. Imparato (New York, NY). I enjoyed your paper. I am curious to know how you arrived at the criteria for the selection of the patients for balloon angioplasty?

Dr Avino. Our vein graft revision criteria were derived from our experiences in the past 10 years, which were similar to those reported by the Montefiore group. We found that nonfocal lesions that were developed in the early postoperative period or in small caliber vein segments had a poor outcome when managed with balloon angioplasty.

Dr Roger M. Hayashi (San Jose, Calif). Your group has always advocated aggressive duplex scan surveillance of grafts, yet despite your aggressive approach to follow-up, approximately 10% to 20% of your grafts will close occultly. You chose, as the basis of your surveillance criteria, a peak systolic ratio of 3.5 or a peak systolic velocity of greater than 300. Do you think your ability to detect some of these occult closures would be improved if you lowered your surveillance standards to levels advocated by others?

Dr Avino. Ten graft failures occurred during surveillance—six were caused by multiple segmental stenosis in a small diameter vein conduit, two from repair site failure, and two from progression of outflow tract atherosclerotic disease. We believe we could slightly improve our occlusion rate by lowering the revision criteria but that this would result in a significantly greater number of revisions.

Dr Jamal J. Hoballah (Iowa City, Iowa). Do you believe that mid-graft stenoses and anastomotic or perianastomotic stenoses respond similarly to balloon angioplasty?

Dr Avino. We found no differences in the success of angioplasty applied to lesions in the vein conduit versus the anastomosis as long as the specific revision criteria were followed (focal stenosis in good caliber vein that developed greater than 3 months after surgery).